

A Sensitivity Study of the Urban Effect on a Regional-Scale Model: An Idealized Case

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9.4 A Sensitivity Study of the Urban Effect on a Regional-Scale Model: An Idealized Case

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1. INTRODUCTION

Urban infrastructure impacts the surface and atmospheric properties, such as wind, temperature, turbulence and radiation budgets. The well-recognized urban heat island phenomenon, characterized by the temperature contrast between the city and the surrounding rural area, is one such impact. Many field experiments have been conducted to study the urban heat island effect, which is typically most intense under clear sky and weak ambient wind conditions at night. In some cases, a cool island may even exist during the day.

To consider these urban effects in a numerical model with horizontal grid resolution on the order of kilometers, some sort of parameterization is required to account for the sub-grid building impacts on these effects. To this end, Brown and Williams (1998) have developed an urban parameterization by extending Yamada's (1982) forest canopy scheme to include drag, turbulent production, anthropogenic and rooftop heating effects, and radiation balance in a mesoscale model. In this study, we further modify this urban parameterization by adding the rooftop surface energy equation to eliminate a simplifying assumption that the rooftop is at the same temperature as the air. The objective of this work is to assess the impact of individual process of this modified urban canopy parameterization for the urban heat island phenomenon.

2. MODEL AND INITIAL CONDITIONS

The Naval Research Laboratory's 3-D coupled Ocean/Atmosphere mesoscale prediction system (COAMPS) is used to study the impacts of the urban canopy on atmospheric momentum and heat transport, and surface energy budget. COAMPS consists of a data assimilation system, a nonhydrostatic atmospheric forecast model, and a hydrostatic ocean model.

In this study, we use only the atmospheric model, which is composed of the compressible form of the dynamics, nest-grid capability, and parameterizations of subgrid-scale mixing, surface momentum and heat fluxes, explicit ice microphysics, subgrid-scale cumulus clouds, and shortwave and longwave radiation. The terrain-following vertical coordinate is also used to simulate flow over an irregular surface. The reader is referred to Hodur (1997) for further details of COAMPS.

The model domain contains 35 grid points in the vertical, with the grid size varied to maximize resolution at lower levels. The grid spacing of the lowest layer is 2 m, with each successive layer depth doubled up to the level of 0.76 km. Above 0.76 km, a uniform grid size of 500 m is used with the domain top residing at 14.01 km. In the horizontal, both zonal and meridional coordinates have 49 grid points with a uniform grid size of 9 km. Time steps of 10 and 5 seconds are used for the time-splitting scheme as a result of high temperature gradient

generated by the rooftop effect. Open radiation and rigid boundary conditions are imposed at the lateral and vertical boundaries, respectively. A sponge-damping layer is placed above 10.5 km to minimize the reflection of internal gravity waves off the rigid upper boundary. A time filter with a coefficient of 0.1 is applied to control computational instability associated with the leapfrog time approximation in the model.

In this research, we conduct a series of sensitivity experiments using idealized initial conditions. The initial conditions of temperature and moisture profiles are given from the midlatitude summer-time standard atmosphere. For simplicity, the horizontal wind is set to be a constant value in the model domain. A constant concentration of carbon dioxide at 300 ppm and a climatological ozone profile from NOGAPS (Navy Operational Global Atmospheric Prediction System) data are used for radiation calculation.

3. URBAN CANOPY PARAMETERIZATION

The main differences between the urban canopy and the forest canopy are (1) the addition of anthropogenic heat source, and (2) further division of the urban canopy fraction (f_{urb}) into roof fraction (f_{roof}) and between-building fraction (f_{cnyl}).

As in the forest canopy, the urban canopy acts as a friction source in the u , v and w momentum equations,

$$\frac{DU}{Dt} = \dots - f_{roof} \cdot C_d \cdot a(z) \cdot U \cdot |U|, \quad (1)$$

where f_{roof} is the horizontal fraction of model grid covered by buildings. C_d is the drag coefficient of the urban canopy, and $a(z)$ the building surface area density profile of the urban canopy.

Unlike the momentum equations, the urban canopy is treated as a source of turbulence production in the turbulence kinetic energy (TKE) equation,

$$\frac{D(TKE)}{Dt} = \dots + f_{roof} \cdot C_d \cdot a(z) \cdot (|U|^3 + |V|^3 + |W|^3). \quad (2)$$

The effect of the urban canopy on the heat equation is more complicated than the one shown in Yamada's forest canopy. The impacts of the urban canopy on the potential temperature equation is expressed by

$$\frac{D\theta}{Dt} = \dots + \frac{1}{\pi \cdot \rho \cdot c_p} \cdot \{(1 - f_{urb}) \cdot \frac{\partial R_N}{\partial z} + f_{urb} \cdot \frac{\partial q_{urb}}{\partial z} + (1 + \frac{1}{B})^{-1} \cdot [(f_{urb} - f_{roof}) \cdot \frac{\partial R_{Nc}}{\partial z} + f_{roof} \cdot b(z) \cdot \frac{\Delta q_{roof}}{C_{roof}}]\}, \quad (3)$$

where R_N and R_{Nc} are net downward radiative fluxes outside and in between-building regions of the urban canopy, respectively, π non-dimensional pressure, ρ air density, c_p specific heat of dry air at constant pressure, and C_{roof} heat capacity of roof. A user-specified profile of bottom-up linearly decreasing anthropogenic heat flux (q_{urb}) is used within the urban canopy.

As in Brown and Williams, we assume that the Bowen ratio (B) is well mixed within the urban canopy, and that $R_{Nc}(z) = R_h^{net \downarrow} \cdot \exp\{-k \cdot L(z)\}$, where $R_h^{net \downarrow}$ is

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the net downward total radiative flux at the top of the urban canopy (h_c), k a user-specified extinction coefficient, and $L(z)$ the cumulative index of building surface area given by $L(z) = \int_z^{h_c} a(z') \cdot dz'$. Without the weighting function of roof fraction $[b(z)]$, this urban parameterization would over-predict the roof nighttime warming and daytime cooling, respectively. Assuming an insulated roof bottom, the heat flux change of the roof surface within the urban canopy is calculated by

$$\Delta q_{\text{roof}} = R_{\text{SW}}^{\downarrow} \cdot (1 - \alpha) + \varepsilon \cdot (R_{\text{LW}}^{\downarrow} - \sigma T_{\text{roof}}^4) + \rho c_p c_{d_roof} |\vec{V}| \cdot (T_{\text{roof}} - T), \quad (4)$$

where $R_{\text{SW}}^{\downarrow}$ and $R_{\text{LW}}^{\downarrow}$ are the downward shortwave and longwave radiative fluxes at the roof surface, α roof albedo, ε roof emissivity, c_{d_roof} drag coefficient of roof surface, $|\vec{V}|$ ambient velocity, T ambient temperature, and T_{roof} roof temperature determined by the roof surface energy equation.

The impact of the urban canopy on the surface radiation budget is treated differently from its counterpart within the canopy by assuming that the heat within the urban canopy is released directly into the air aloft. Therefore, the anthropogenic and rooftop heating terms are assumed to have no impact on the surface net total radiative flux (R_{NG}),

$$R_{\text{NG}} = (1 - f_{\text{urb}}) \cdot (R_{\text{SW}}^{\text{net}\downarrow} - R_{\text{LW}}^{\text{net}\uparrow})_G + f_{\text{cnyrn}} \cdot [R_{\text{Nc}}(0)]_G, \quad (5)$$

and the surface energy equation,

$$\frac{\partial T_G}{\partial t} = R_{\text{NG}} - H_G - L_G - S_G, \quad (6)$$

where T_G , H_G , L_G , and S_G are surface temperature, sensible heat flux, latent heat flux, and soil-layer heat flux, respectively.

4. RESULTS AND SUMMARY

In this study, the urban region is specified at the center of the model domain with a size of 8×8 grid points. Our results indicate that the urban drag acts to strengthen nocturnal eddy kinetic energy production and to enhance the upward TKE transport for both modified and Brown & Williams urban canopy schemes (not shown). However, prominent differences exist in the heat equation between these two schemes (Fig. 1). The addition of rooftop surface energy equation in the modified scheme leads to a more reasonable diurnal cycle of the heat island effect, which replicates the nighttime warming with the maximum near the sunrise and daytime cooling as observed. This warming/cooling intensifies with the increasing roof fraction. The larger roof fraction also causes a longer time lag of temperature rising near the sunrise in response to a larger heat capacity of rooftops.

In general, our modified urban canopy scheme exhibits a reasonable relationship of the heat island effect with the urban canopy size. More interesting

results will be shown to assess the overall performance of this modified urban canopy scheme.

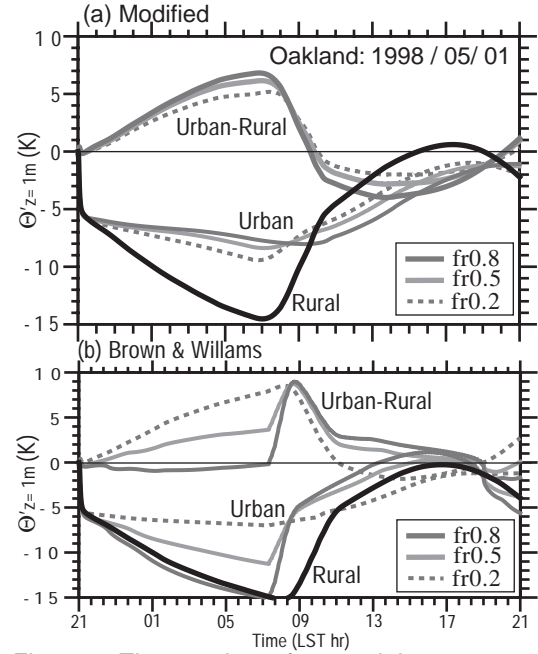


Fig. 1. Time series of potential temperature anomaly to the initial state at 1 meter above the surface for roof fractions of 0.2, 0.5 and 0.8, respectively. Simulations shown are based on the same urban canopy parameters ($f_{\text{urb}} = 0.9$, $q_{\text{urb}} = 20 \text{ W/m}^2$, $h_{\text{urb}} = 30 \text{ m}$, $U = 10 \text{ m/s}$). (a) modified urban canopy scheme. (b) Brown and Williams scheme.

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5. REFERENCES

- Brown, M. J. and M. Williams, 1998: An Urban Canopy Parameterization for Mesoscale Meteorological Models. *Proceedings of the AMS Conference on 2nd Urban Environment Symposium*, 2-7 November, 1998, Albuquerque, New Mexico, Amer. Meteor. Soc., 144-147.
- Hodur, R., 1997: The Naval Research Laboratory's coupled ocean-atmospheric mesoscale prediction system (COAMPS). *Mon. Wea. Rev.*, **125**, 1414-1430.
- Yamada, T., 1982: A numerical model study of turbulent airflow in and above a forest canopy. *J. Meteor. Soc. Japan*, **60**, 439-454.